

# PAMIR-3U MAGNETOHYDRODYNAMIC GENERATOR RESULTS

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## ABSTRACT

The Air Force's Phillips Laboratory has acquired a high power magnetohydrodynamic (MHD) generator for possible use with advanced weapons applications. This MHD generator is a PAMIR-3U, a modified Russian-built MHD generator that uses a modified rocket fuel to produce a DC electrical pulse of 100 MJ. The PAMIR-3U generator produces tens of kA at 800 V for an optimized load of  $(20 \pm 5) \text{ m}\Omega$ . A review of the MHD generator design and results of the generator acceptance testing is presented. The PAMIR-3U generator was constructed by the Institute of High Temperatures of the Russian Academy of Sciences (IVTAN) and delivered to the Air Force's Phillips Laboratory under contract with Textron Defense Systems (TDS) of Everett MA.

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This work was performed for the Phillips Laboratory under Contract Number F29601-93-C-0033.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>JUL 1995</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>PAMIR-3U Magnetohydrodynamic Generator Results</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>High Energy Plasma Division; PL/WSP Phillips Laboratory Kirtland AFB NM 87117-5776</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.</b>					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>	18. NUMBER OF PAGES <b>6</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## INTRODUCTION

In this paper, we present the results of the acceptance testing of the Phillips Laboratory Russian-designed and built PAMIR-3U MHD generator. The PAMIR-3U, based on the MHD generators used in Russia for over 20 years, is specially designed for US operations. Designed to be a transportable power supply for use in field situations, it is able to fit in a volume defined by 8' (2.44 m) by 8' (2.44 m) by 34' 8" (10.57 m) and weighs no more than 40,000 pounds (18,100 kg). The PAMIR-3U is designed to produce 100 MJ of electrical energy to a fixed ( $20 \pm 5 \text{ m}\Omega$ ) load, for times ranging from 6 to 10 seconds with powers ranging from 8 to 15 MW<sub>e</sub>. The eight acceptance tests were supervised by the TDS contractor at the Aerojet Propulsion Division (APD) subcontractor test site in Sacramento CA.

The Phillips Laboratory acquired a PAMIR-3U MHD generator under contract with TDS. As part of the contract, TDS was to perform acceptance tests to indicate successful operation of the MHD generator. These tests were performed at the APD test site with operations led by the Russian subcontractors. The acceptance tests were performed from 10 February to 1 March 1995.

The PAMIR-3U uses a modified solid rocket fuel manufactured by Soyuz to create a plasma flow in the MHD generator channel. (The rocket fuel is modified by adding CsNO<sub>3</sub> to increase the conductivity of the burn reactants.) Before the rocket fuel is ignited for power generation, the Initial Excitation System (IES) is used to produce a low level magnetic field in the field coils. Plasma current flowing through the plasma channel volume produces a magnetic field in the generator magnets. The plasma interacts with the generator magnetic field to induce a voltage in the plasma channel electrodes. Power is produced from tapping the voltage from the plasma channel electrodes. (Generator current not fed to the magnets provides power to the load.)

The acceptance testing was divided into three kinds of runs: 1) long duration, low power; 2) nominal duration, nominal power; and 3) short duration, high power. Long duration runs were 9 seconds of power production. Low power runs produced 10 MW<sub>e</sub> to the load. Nominal duration runs were 7.5 seconds. Short duration runs were 6.5 seconds and produced 13-14 MW<sub>e</sub> to the load.

The summary for all eight acceptance runs is presented in the following table.

Table. PAMIR-3U Acceptance Testing Summary

Shot No.	Avg. Power <sup>1</sup> (MW)	Peak Power (MW)	Time, Power to Load <sup>2</sup> (s)	Fuel T <sup>3</sup> (°C)	Avg. Channel Pressure (atm)	Plasma Generators? <sup>4</sup> (Y/N)	New MHD Channels? <sup>5</sup> (Y/N)	Ballast R <sup>6</sup> (mΩ)	Load R (mΩ)
1	12.6	13.5	6.72	35	46	Y	Y	24	20
2	13.3	13.6	6.48	35	46	Y	Y	16	20
3	12.9	13.3	6.69	35	45	N	N	18	15
4	13.7	14.6	6.2	42	48	Y	Y	8	15
5	10.2	10.4	8.96	0	34	N	N	18	15
6	10.4	10.8	7.5	20	40	N	N	20	25

7	10.3	10.8	10.37	0	30	N	N	12	15
8	14	14.9	6.43	42	48	Y	Y	14	15

- <sup>1</sup> The average output power is determined from the average during the power delivery to the load.
- <sup>2</sup> The power to load time is calculated from the first occurrence of the 50% of peak power to the last occurrence of 50% of peak power. Acceptance test number 7 did not use the switches of the other acceptance tests; the power for this test rose slowly (instead of being switched to the load in tens of milliseconds).
- <sup>3</sup> The fuel temperature is the fuel conditioning temperature; it is conditioned at the given temperature for 24 hours before being inserted in the MHD generator. After removal from temperature conditioning, a three-hour window was allowed for MHD generator firing.
- <sup>4</sup> A limited number of plasma generators were provided for operations, so they were refurbished after operation. Plasma generators were designed for three uses.
- <sup>5</sup> A limited number of MHD generator channels were provided for operations, so they were refurbished after operation. Like the plasma generators, MHD generator channels were designed for three uses.
- <sup>6</sup> The ballast resistance is adjusted to control the current delivered to the generator magnets. The larger the ballast resistance, the smaller the current delivered to the generator magnets.

Three parameters were used to control or modify the electrical power delivery to the load: 1) fuel temperature; 2) switch timing; and 3) use of new or reconditioned components.

The temperature of the fuel affected the fuel burn time and the amount of electrical power delivered to the load. Although the fuel was rated for operations from 0 to 35°C, two acceptance runs were performed with the fuel conditioned to 42°C. Reducing the fuel temperature increased the burn time, but reduced the electrical power delivered to the load. Increasing the fuel temperature decreased the burn time, but increased the electrical power delivered to the load.

The optimum timing for switching out the IES and switching the electrical energy to the load was determined in advance by computer simulation and input into the system control via the Computer Monitoring, Measurement and Recording System (CMMRS). Switches were explosively driven opening and closing switches. Switching times were on the order of tens of milliseconds.

Maximum power was obtained by using new components. Using reconditioned MHD generator components (MHD generator channels and plasma generators) dropped the electrical power delivered to the load.

## RESULTS

The results of the MHD generator acceptance tests are seen in Figures 1-6. In each Figure, a series of current, voltage and power traces are presented. The current traces show an overlay of the load, plasma channel 1, plasma channel 2 and magnet currents as recorded by the CMMRS. (The IES current is also plotted in the current overlay, but since it goes to 0 when the load current comes on, it is not very interesting.) The load, channel and magnet currents over time due to heat-induced resistance increases. The voltage traces show an overlay of the magnet, load and channel voltages (taken from the CMMRS data). The magnet voltage reverses at the end of power delivery. The power trace is calculated from the CMMRS load and current voltage data.

### Acceptance Shot 1

The first active acceptance shot was fired on 10 February 1995. This was designed to be a maximum power test. For that reason, the fuel was conditioned to 35°C. Data is presented in Figure 1.

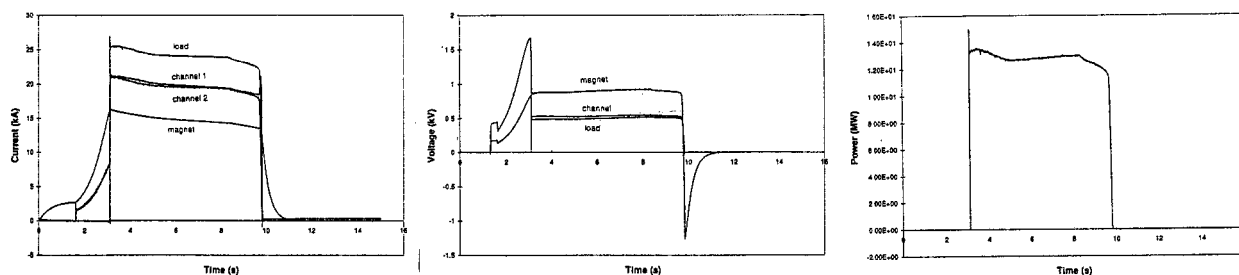


Figure 1. Data for acceptance shot 1.

### Acceptance Shot 2

The second acceptance shot was fired on 14 February 1995. This was a maximum power test. The fuel was conditioned to 35°C. Data is presented in Figure 2.

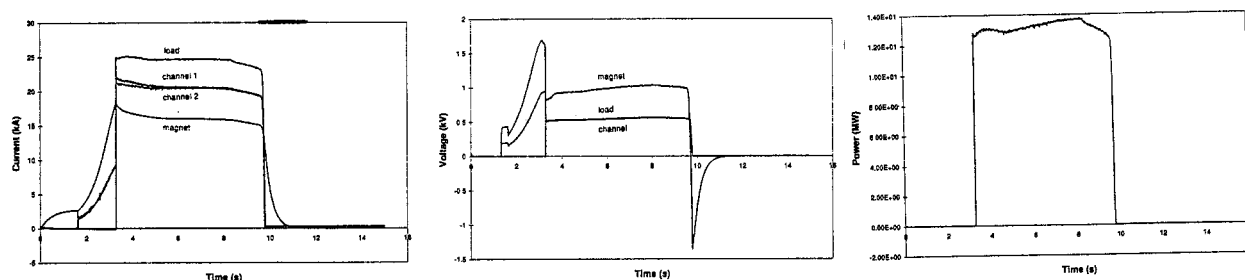


Figure 2. Data for acceptance shot 2.

### Acceptance Shot 3

The third acceptance shot was fired on 17 February 1995. This was another maximum power test. The fuel was conditioned to 35°C. The data is presented in Figure 3.

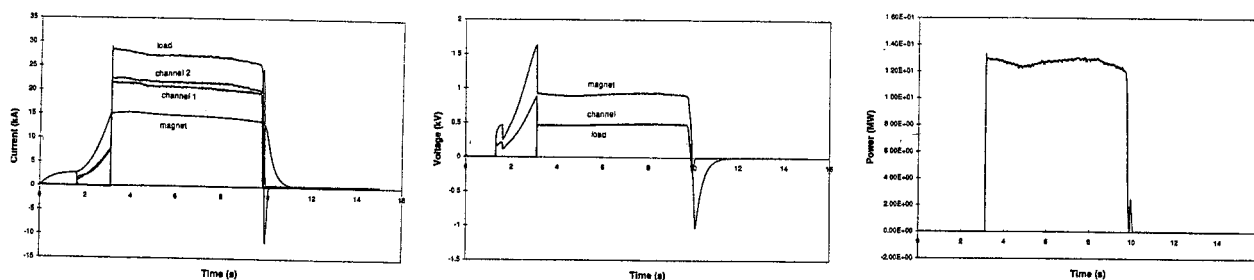


Figure 3. Data for acceptance shot 3.

### Acceptance Shot 4

The fourth acceptance shot was fired on 20 February 1995. This was another maximum power test. The fuel was conditioned to 42°C. The data is presented in Figure 4.

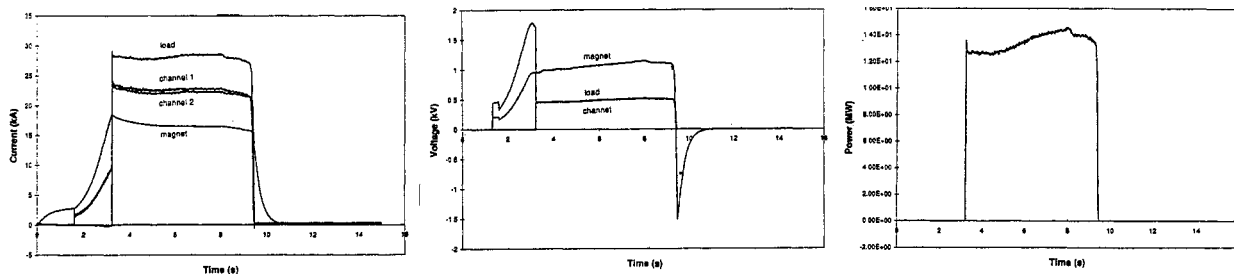


Figure 4. Data for acceptance shot 4.

### Acceptance Shot 5

The fifth acceptance shot was fired on 22 February 1995. This was a maximum duration test. The fuel was conditioned to 0°C. The data is presented in Figure 5.

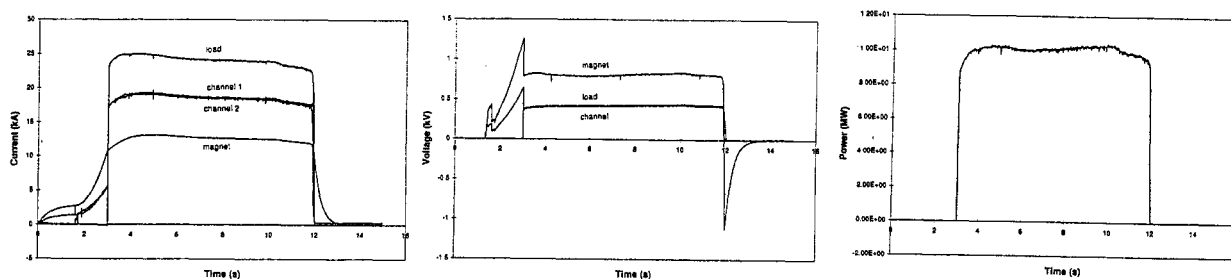


Figure 5. Data for acceptance shot 5.

### Acceptance Shot 6

The sixth acceptance shot was fired on 24 February 1995. This was a nominal power, nominal duration test. The fuel was conditioned to 20°C. The data is presented in Figure 6.

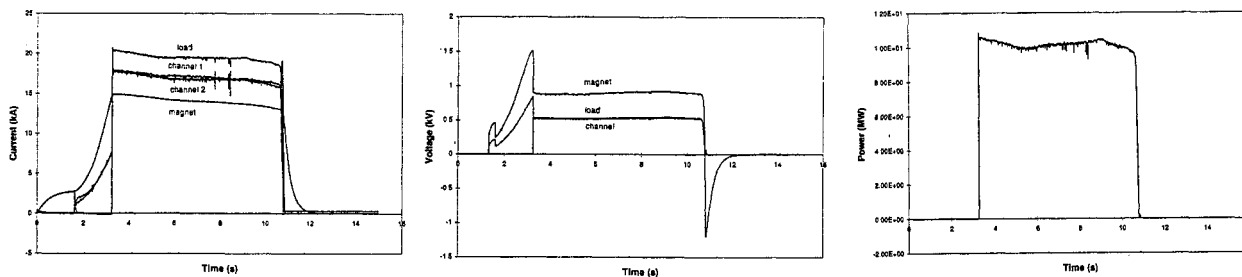


Figure 6. Data for acceptance shot 6.

### Acceptance Shot 7

The seventh acceptance shot was fired on 27 February 1995. This was another maximum duration test. The fuel was conditioned to 0°C. The data is presented in Figure 7.

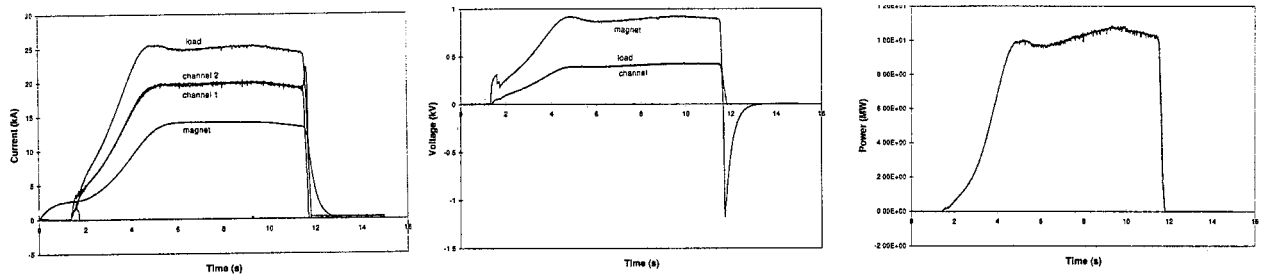


Figure 7. Data for acceptance shot 7.

### Acceptance Shot 8

The eighth, and last, acceptance shot was fired on 1 March 1995. This was another maximum power test. The fuel was conditioned to 42°C. The data is presented in Figure 8.

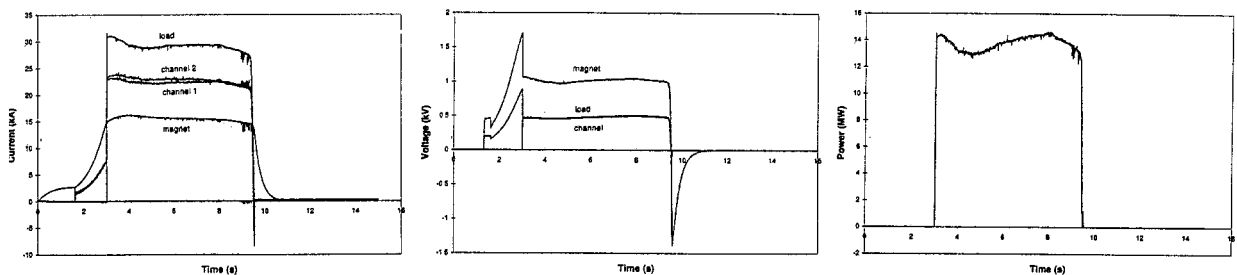


Figure 8. Data for acceptance shot 8.

## SUMMARY

The acceptance testing for the Phillips Laboratory Russian-built PAMIR-3U MHD generator showed it can perform at the required specifications. This proof of concept for a basic MHD generator like the PAMIR-3U indicates that similar MHD generators may be used for specialized applications as transportable power supplies under field conditions.